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STUDY OF A FILMLESS TECHNIQUE AND RADIOGRAPHIC METHOD FOR TESTING OF WELDS IN BUTT JOINTS OF TANKERS T-2

By

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ABSTRACT

Tests performed on a welded steel plate with artificial defects proved the feasibility of more expeditious methods of inspecting welds of tankers by: (1) Improvement of Radiographic methods by X-rays or Gamma rays and by, (2) using isotopes as radiation sources and Geiger-Muller counters as detectors. ()

On the basis of experiments performed on a welded steel plate it was found that the cost of radiography by X-rays of 1500 ft of critical linear weld on tankers T-2 should not exceed $1100, allowing a liberal profit for the contractor. With three operators, the time required for the inspection would amount to about 25 hr.

By application of two Cobalt 60 isotopes, each 2000 mc, the welds concerned could be inspected by four operators in about 41 hr at a cost of about $985 per tanker.

Although the feasibility of the Geiger counter method was shown, it is necessary to do further development in order to improve the economy of the method.

Data on the effective size of the voids determined by the film and by the filmless method were found to be in satisfactory agreement.

[redacted]

FOREWORD

The methods for inspection of welds described in this report, while not fully developed, appear promising. It appears feasible to develop a filmless method of weld inspection which would be both less expensive and less bothersome than methods requiring films.

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P. A. LONGWELL
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INTRODUCTION

At the meeting of the Defense Conference on Nondestructive Testing, Washington, D.C., 19 through 20 November 1952, the problem of testing welds on tankers T-2 was submitted by LCDR M. Hinkamp, Bureau of Ships. Because very catastrophic failures on two tankers T-2 occurred recently, the most urgent and pressing requirement was to prevent such failures. It is assumed, according to LCDR Hinkamp, that one of the vital causes of failures is the welds in the midship structures. Seven butt joints in the midship portion totaling more than 1500 ft of linear weld are considered critical. At present these joints are radiographically inspected during the 5-day overhaul of a tanker in dry dock. The cost of such an inspection is in the neighborhood of $5000 using gamma radiography with two sources and a team of four men working at odd hours.

As a member of the radiographic panel of the Defense Conference the author volunteered to investigate a filmless technique using a welded steel plate with artificial defects. Subsequently, the author conducted experiments at the Naval Ordnance Test Station, Inyokern, Salt Wells Pilot Plant, in order to find an expeditious filmless test method.

DISCUSSION

GENERAL

A welded steel plate 1 in. thick with artificial defects was supplied by Naval Shipyard, Long Beach, California, and was used as a test object. (See Fig. 1)

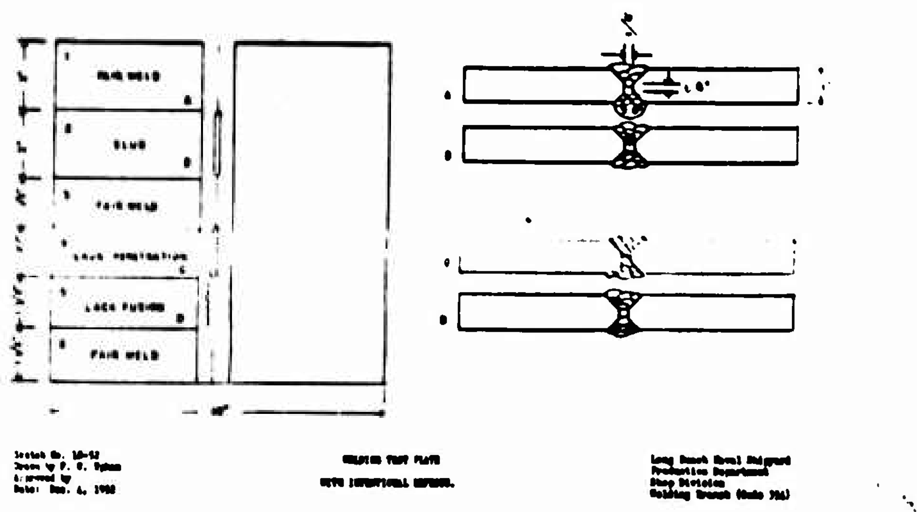

Fig. 1. Identification of defects in the welded steel plate.

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RADIOGRAPHIC METHOD

Since it was important to identify the actual location and extent of the artificial defects, the weld was radiographed and a film was obtained (see Fig. 2 which is a contact print of the original film).

The applied technique was:

Radiation source:	GE 250 KVP Industrial X-Ray Equipment
Tube voltage:	250 KVP
Tube current:	10 MA
Source-film-distance:	36 in.
Exposure time:	3 min
Metal X-ray film cassette loaded with:	0.005 Pb, film, film, 0.005 Pb
Film type:	DuPont No. 506
Developing time:	8 min at 68°F

Although the quality of the film appeared very satisfactory, the use of X-ray equipment on ships (even if mobile) is probably difficult as compared with a radioactive isotope; therefore, a gammagraphic technique was established also. The gammagraphic method chosen employed the most modern techniques for reduction of the exposure time[1]. The drastic reduction in the exposure time was obtained by the application of high-speed intensifying (calcium tungstate) screens. In order to reduce the Compton scatter effect on the intensifying screens, a heavy metal filter of 0.25 in. lead was inserted between the object and film cassette. The photoelectric scatter of lead was eliminated by a brass filter.

GAMMAGRAPHIC METHOD

Figure 3 is the contact print of the gammagraph which was taken by the following technique:

Radiation source:	2800 mc (Equiv. to 4200 mc radium) isotope Cobalt 60
Source-film-distance:	41 in.
Exposure time:	3 min
Metal cassette loaded:	Eastman Kodak "F" film between two Patterson high speed screens.
Developing time:	6 min

The comparison of the two films, radiographic and gammagraphic, proves the superior quality of the radiograph. However, the gammagraph also appears satisfactory as to the location, relative depth, and the extent of the defects.

1) Navord Report 2666, "Gamma Ray Sources and Techniques for Gamma Ray Radiography", 26 Feb 1953

[redacted]

Fig. 2. Contact print of radiograph.

In order to determine the equivalent depth of the defects, measurements with Weston densitometer were performed on the radiograph (Fig. 2). The test points are indicated on Fig. 2 and the corresponding densities are shown in Table 1.

TABLE 1

Determination of Weld Thicknesses By the Radiographic Method

Test Pos. No.	Film density*	Log rel Exp. (Log E_x)	Equiv. Thickness of welds (in.)	Equiv. Defect Depth (in.)	Defect in % of fair weld
1	1.80	2.10	1.223	0.027	2.2
2	2.51	2.26	1.154	0.096	7.7
3	2.26	2.21	1.176	0.074	5.9
4	1.54	2.03	1.250	0.0	0.0
5	2.28	2.22	1.172	0.078	6.2
6	1.99	2.15	1.202	0.048	2.8
7	1.39	1.98	1.275	---	---

* In units of density according to Hurter and Driffield.

Computations for the determination of the thickness of the weld are given in Appendix 1 to this report. The effective thickness values from Eq. 6 of Appendix 1 are listed in Table 1 above, together with the values for the equivalent defect depth and its value in percentage.

It is noteworthy that the maximum defect does not exceed 7.7 percent. On the basis of this value, it can be concluded that the maximum admissible defect of 15 percent in a critical weld can be easily detected.

GEIGER COUNTER METHOD

As the writer has been developing a nondestructive method for determination of densities in certain parts of SWPP product by application of isotopes and Geiger counters, the same method was used to determine the equivalent thicknesses in various parts of the test weld plate. Figure 4 illustrates the principle of the experimental arrangement.

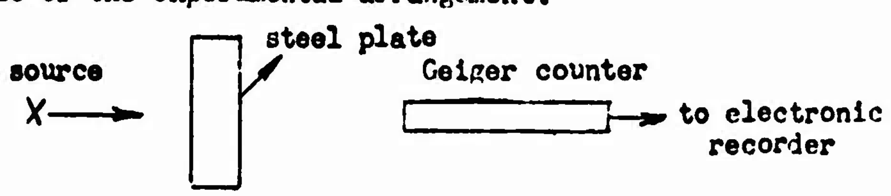

Fig. 4. Diagram of the principle of determination of thicknesses by Geiger method.

A block diagram of the electronic system of the Geiger detector is indicated in Fig. 5.

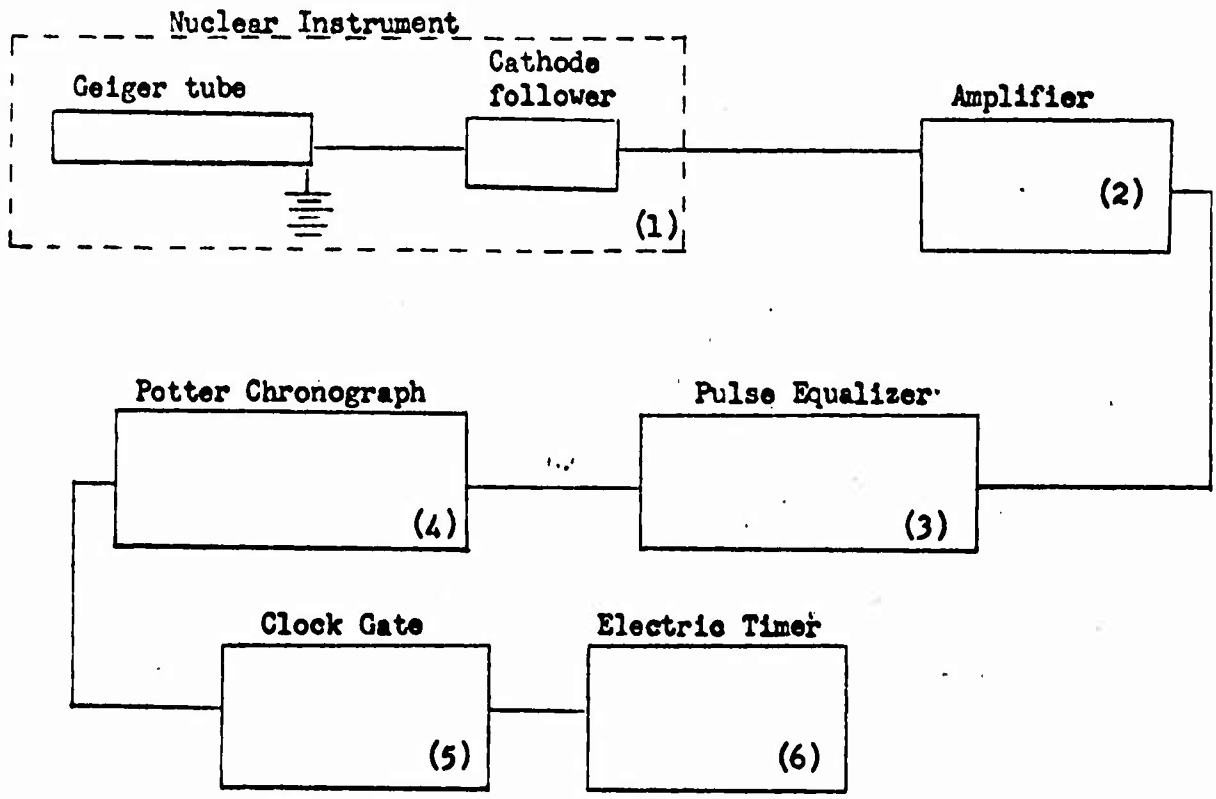

Fig. 5. Block diagram of electronic system of Geiger detector.

Since a high level energy source (Cobalt 60) of high intensity (300 mc) was used, it was necessary to protect the Geiger detector from any scattered radiation. This was achieved by encasing the gamma source and the Geiger tubes (three tubes were used simultaneously for better statistical results and reduction of the experimental time) in their corresponding lead containers, leaving only a small bore for the radiation beam (See Fig. 6).

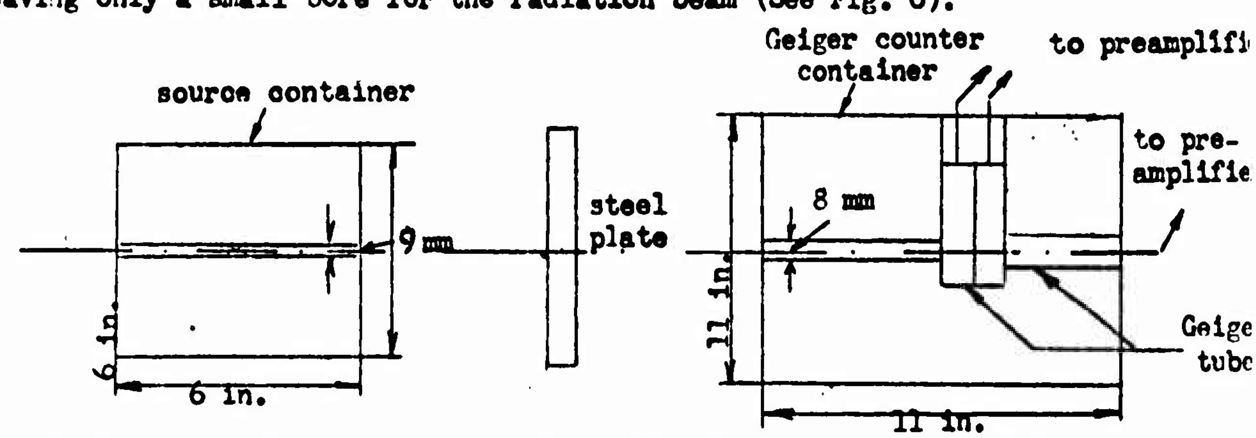

Fig. 6. Experimental arrangement of the radiation source, steel plate, and Geiger tubes.

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The applied method is based on the phenomenon that a part of the primary gamma radiation is absorbed in the specimen and the transmitted part of quanta reaches the Geiger tube. In the latter the quanta cause ionization of the gaseous content and in discharging the Geiger tube originate an electric pulse.

The electric pulses are counted by the Potter Chronograph. The number of counts in the latter is set for a certain value while the simultaneous start and stop of a counting series and of an electric or electronic timer is electronically controlled so that the time required for a certain number of pulses is determined by the timer. Consequently, there is a direct relation between the absorption of the radiation intensity in the specimen and the recorded time.

The positioning of the steel plate was not accurate enough to guarantee that for every experimental point on the weld the gamma ray beam will penetrate the latter centrally. As a result of this condition at some experimental points the recording of the absorption was not exactly proportional to the defect size. Since the diameter of the bore in the Geiger container is about 8 mm and the width of the weld about 3 mm, it is evident that the radiation beam penetrated not only the defect on the weld, but also a part of the solid material. Therefore, different absorption values might be obtained as a result of any eccentricity of the beam with respect to the weld defect.

For identification of the measurement points, two holes about 1/8 in. in diameter and about 1 in. from the edge of the plate were drilled through the weld. The hole on the side of the plate marked "I" (Fig. 2) was used as a reference point.

The experimental data and the computed thicknesses for the Geiger method are listed in Table 2 (see Appendix 1 for additional computations on weld thicknesses).

The values t_x are averages of two readings and are plotted in Fig. 7 against the distances from the reference hole. The corresponding test points on the radiograph (Fig. 2) are identified by Roman numerals. The values of the film densities and Geiger counter readings expressed in seconds demonstrate a satisfactory agreement.

The agreement between these two methods is generally satisfactory as shown in Table 2, Columns IV and VI. The agreement is not exact as the points of the two methods do not coincide precisely and by the densitometric method a much smaller area of the film is covered (about 3 mm diameter) than that covered by the diameter of the radiation beam (about 8 mm).

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[redacted]

TABLE 2

Experimental Data of the Geiger Method and Comparison With the Radiographic Method

GEIGER METHOD				RADIOGRAPHIC METHOD	
I	II	III	IV	V	VI
Pos. No.	Distance from hole (mm)	Time* (sec) t_x	d_x	Pos. No. of considered points	Thickness corres. to Col. IV
	-15			1	1.223
1	-10	37.36	1.198		
2	- 5	37.65	1.204		
3	0	27.40	0		
4	+ 5	38.00	1.210		
5	+15	36.97	1.19		
	+23			2	1.154
6	+25	33.52	1.100		
7	+35	37.15	1.193		
8	+45	37.13	1.193		
9	+55	37.53	1.200		
10	+67			3	1.176
10	+65	36.36	1.178		
11	+75	37.88	1.208		
12	+85	38.99	1.228		
13	+95	39.91	1.250		
	+98			4	1.250
14	+115	36.93	1.188		
	+120			5	1.172
15	+125	36.43	1.178		
16	+135	37.51	1.200		
17	+145	38.26	1.213		
18	+155	36.04	1.170		
19	+165	37.59	1.202		
20	+175	36.51	1.180		
	+183			6	1.202
21	+185	36.96	1.190		
22	+195	38.95	1.23		
23	+210	39.55	1.24		

*Average of two readings

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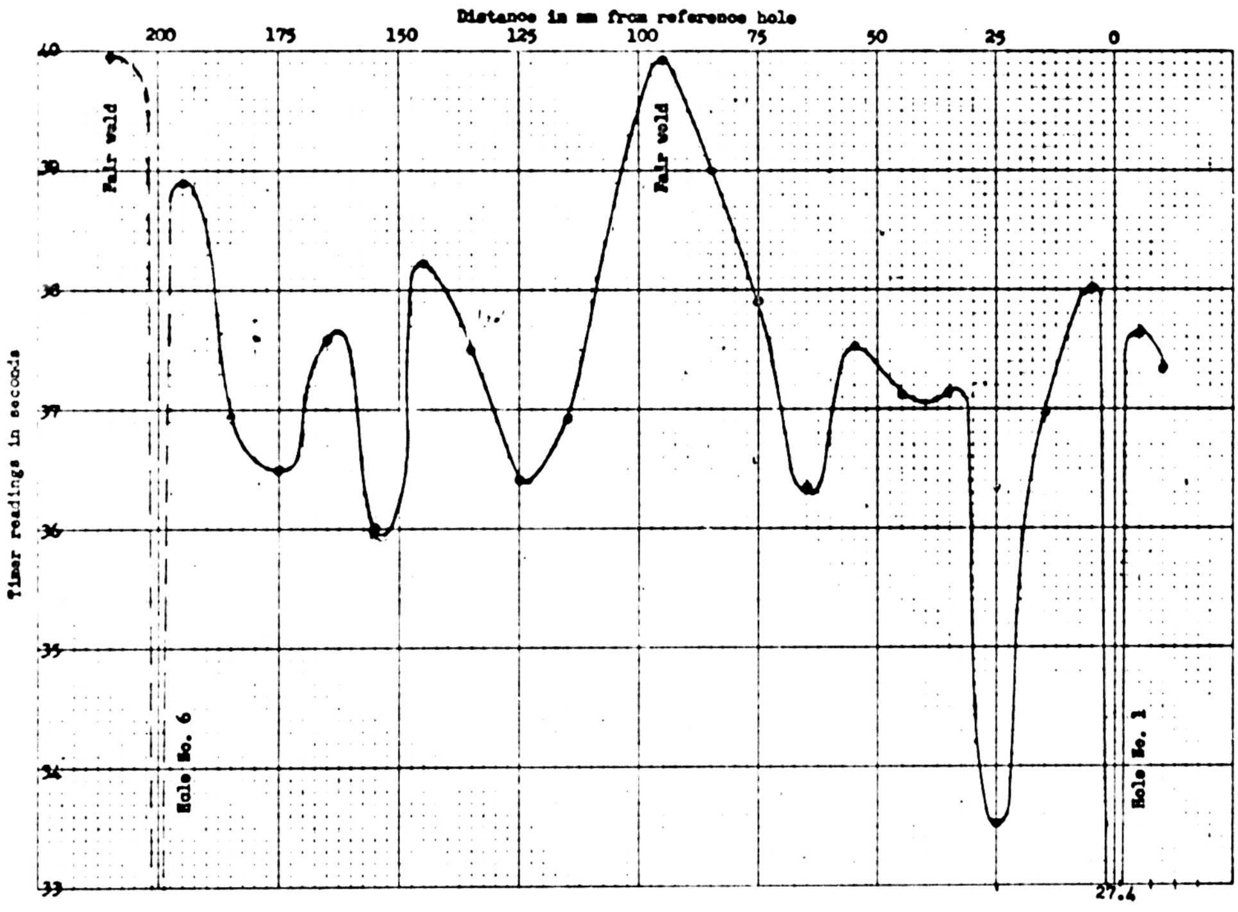

Fig. 7. Geiger Method. Timer readings at various points of the weld.

[redacted]

Since the area of the radiation beam (about 8 mm) covered not only the width of the weld (3-4 mm) but also a part of the solid steel, it could be expected that by application of an appropriate diaphragm more satisfactory results could be obtained. Preliminary experiments with a rectangularly shaped diaphragm proved this assumption.

The further improvement of the Geiger method would require the development of a ratemeter for the detector. The ratemeter would indicate the number of transmitted radiation quanta through the weld per unit time. It seems feasible to design a ratemeter not requiring more handling and operating time than the above Geiger counting equipment. Moreover, the cost of the ratemeter equipment would be half as expensive as the scaler equipment. The ratemeter would of course be considerably less accurate than the scaler but high a instrument accuracy is not required for this application.

Since labor represents the most significant item in the total cost for the Geiger method, the increase of number of ratemeters per unit appears to be the most effective solution for decreasing labor cost. By simultaneous covering of a longer length of the weld during a single examination, the number of movements of the equipment from one weld part to another and labor cost can be reduced considerably.

The cost estimates for the two methods are given in Appendix 2 of this report.

The Geiger method can be modified by positioning the radiation source and the Geiger counter on one side of the ship wall as indicated in Fig. 6a. By this arrangement the necessary alignment of the radiation source and the camera with respect to each measuring position is eliminated. Furthermore, if the Geiger counter and the radiation source are located outside the bulk head, minimum interference is expected with other activities inside the ship during overhauling of the tanker.

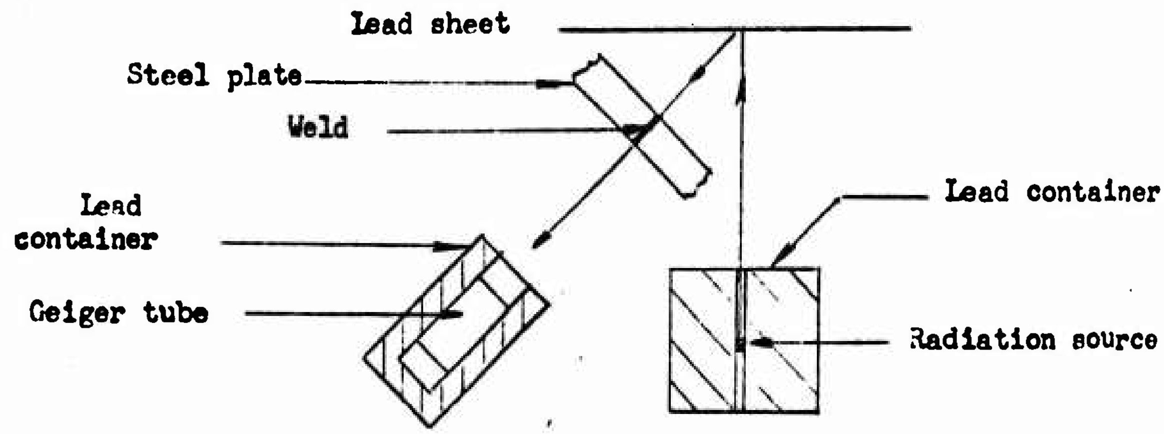

Fig. 6a. Schematic illustration of the test arrangement for use of characteristic radiation of lead.

The effect of the method is based on utilization of the characteristic radiation emitted from the radiator such as lead, uranium, etc., in general, of elements of high atomic number.

The feasibility of the method was proven by preliminary experiments in which 300 mc of Cobalt 60, one Geiger counter, and 1/2 in. steel as absorber were used. The corresponding time indicated by the electric timer was 430 divisions. Since 1/2 in. is equivalent to 12.5 mm, 1 mm represents roughly a variation of about 35 divisions (0.35 of one revolution). Considering 15 percent effective thickness as the maximum permitted defect in the weld for a total weld thickness of 1 1/4 in., a minimum of 4.6 mm effective thickness of the weld would have to be detected. According to the foregoing 4.6 mm represent about 160 divisions (1.6 revolution) and will be easily detected. This method can be further improved by determining simultaneously the absorption in a steel standard and the absorption of the reflected beam in the weld. The sensitivity of the method can be increased by combination of two Geiger counters and two gamma sources in bucking circuit system indicating the differences of effective thicknesses in the steel standard and weld. Because of the comparatively large time difference obtainable with a 15 percent defect in the weld it is believed that a simple ratemeter instead of the present scaler can be designed.

CONCLUSIONS

It follows from Table 2 that a Geiger counter reading for a single test point covering about 3/8 in. of weld required about 1/2 min. Since with the radiographic method only 3 min are required for 3 ft (36 in.) of weld, it is evident that the proposed modified radiographic method is considerably faster than the Geiger method. However, it is believed that the latter by further development in the direction of the design of a ratemeter can be made at least as expeditious as the radiographic method.

By positioning both the Geiger counter and the radiation source outside the bulk head the Geiger method can be considerably simplified; therefore, it is recommended to develop the method in this direction. It is expected that by application of a ratemeter the inspection cost can be considerably reduced.

As shown in Appendix 2, the cost of the radiographic method should not exceed $1100, and with three operators the time required for inspection would amount to about 25 hr. By the use of Cobalt 60 isotopes, inspection could be performed by four operators in about 41 hr at a cost of about $985 per tanker.

[redacted]

APPENDIX 1

COMPUTATIONS FOR DETERMINING WELD THICKNESSES BY BOTH METHODS

RADIOGRAPHIC METHOD

The thickness of the weld at any point can be determined from the classical absorption equation.

$$\frac{I_1}{I_o} = e^{-\mu d} \qquad (1)$$

where

I_o = the primary intensity of radiation

I_1 = the transmitted intensity of radiation

μ = the X-ray absorption coefficient for steel at the effective wavelength of the applied radiation

d = the thickness of the weld

In the following equations d_o designates the thickness of the "fair weld" which is assumed as 1 1/4 in. (1 in. steel plate plus two 1/8 in. thicknesses of the weld bead) and d_x the thickness of the weld at the point where the film density was determined, I_x the radiation intensity corresponding to d_x.

$$\frac{I_o}{I_x} = e^{-\mu (d_o - d_x)} \qquad (2)$$

The radiation intensities and the film densities are related to each other by the equation

$$\frac{I_o}{I_x} = \frac{E_o}{E_x} \qquad (3)$$

where E_o and E_x indicate the respective film "exposures".

By taking a logarithm of Eq. 2

$$\log I_o - \log I_x = -\mu(d_o - d_x) \log e = \log E_o - \log E_x \qquad (4)$$

Log E_o and log E_x correspond to the film density values of Fig. 8.*

* Radiography in Modern Industry, Eastman Kodak Co., Rochester N.Y., 1947

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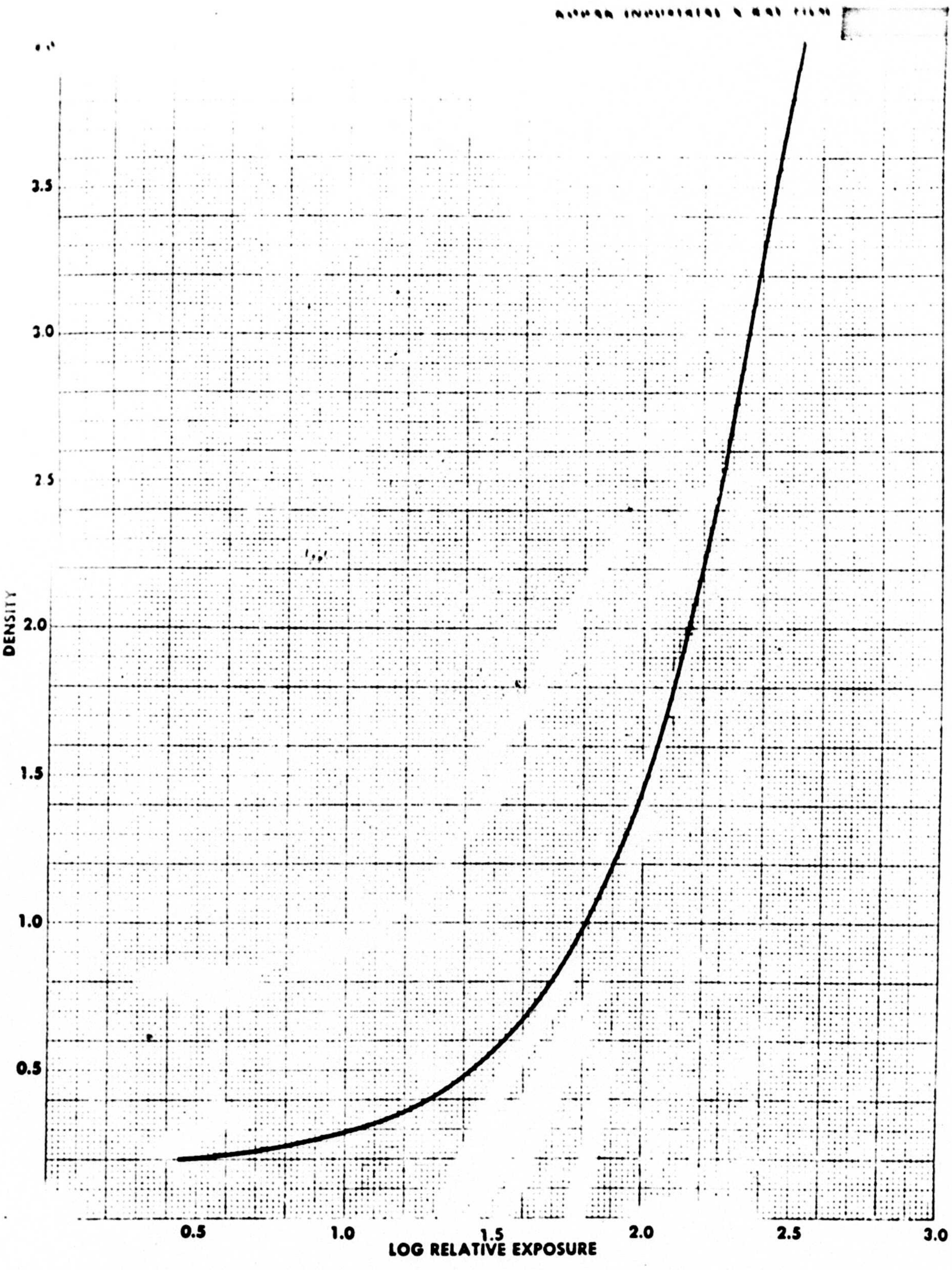


Fig. 8 —Characteristic curve of *Kodak Industrial X-ray Film*, Type A, with direct or lead foil screen x-ray exposure.

APPENDIX 1
(Cont'd)

From Eq. 4

$$d_x = \frac{\log E_o - \log E_x}{\mu \log e} - d_o \qquad (5)$$

The effective wavelength λ eff of the applied radiation source is computed from the equation $\lambda \text{ eff} = \frac{12.35}{\text{KV eff}}$ *.

It was assumed that the applied 250 KVP corresponded to 125 KV eff; thus, λ eff = 0.0988.

From the tables** the X-ray absorption coefficient for steel was found to be:

$$\frac{\mu}{\rho} = 0.265 \text{ and } \mu = 8.x\ (0.265) = 2.120$$

In accordance with Table 1 and Fig. 4, the film density corresponding to the "fair weld" is 1.54 and $\log E_o = 2.03$.

By inserting in Eq. 5 the value 2.03 for $\log E_o$ and 0.434 for log e and using 2.54 for conversion of inches to centimeters, the equation can be written:

$$d_x = 2.12 - \frac{\log E_x}{2.33} \qquad (6)$$

The effective thickness values are computed from Eq. 6.

GEIGER COUNTER METHOD

Analagously to the computation of the equivalent defect thickness by the radiographic method discussed before, the equivalent thickness of the weld at any measured point can be determined from the values of the recorded time.

In Eq. 5 the values of E (exposure) was substituted by time.

Therefore,

$$d_x = \frac{\log t_o - \log t_x}{\mu \log e} - d_o \qquad (7)$$

* Handbook of Industrial Radiology, J. A. Crowther 1949, Edward Arnold & Co., London

** Handbook of Chemistry & Physics, 31st Ed., Chemical Rubber Publishing Co., 19

[redacted]

APPENDIX 1
(Cont'd)

where

d_o = thickness of the "fair weld", assumed 1 1/4 in.

t_o = corresponding time in seconds

μ = X-ray absorption factor of steel for Cobalt 60 radiation

log d = 0.434

d_x, t_x = thickness and corresponding values of time for any point of the weld.

In order to simplify Eq. 7, the constant coefficients were determined.

$\mu = \frac{\mu}{\rho} \cdot \rho$ where ρ = density of steel and $\frac{\mu}{\rho}$ = X-ray mass absorption factor for steel

assumed ρ = 8 gm/cm^3 for steel

$\frac{\mu}{\rho}$ depends on the effective wavelength which is 1.2 meV for Cobalt 60.
The wavelength is computed from $\lambda = \frac{12.35}{1,200\ KV}$ * to approximately 0.01 Å.
$\frac{\mu}{\rho}$ for .01 Å and steel is 0.058, μ = 0.464. Since d is expressed in inches, μ log e is to be multiplied by 2.54. The final equation is:

$$d_x = \frac{\log t_x}{0.51} - 1.89 \qquad (8)$$

and the values (d_x) in Table 2 are derived from this equation.

*Handbook of Industrial Radiology, J. A. Crowther 1949, Edward Arnold & Co., London

APPENDIX 2

COST ESTIMATES

RADIOGRAPHIC METHOD

<u>Film</u>

A strip of 2 in. x 17 in. X-ray film costs about $0.09. Therefore, 1500-ft weld requires about 1575 ft of film tantamount to 1112 strips each 17 in. long, at a total cost of $99.08.

<u>X-Ray Machine</u>

There are mobile X-ray machines on the market, such as Fig. 9 illustrates. The diameter of the tube head is only 15 in., the length 44 in., and the weight only 150 lb; therefore, it can be easily positioned if mounted on a mobile cart even in difficult corners of a tanker.

The cost of the machine is about $16,000. On the assumed basis of 1000 hr lifetime and $1000 price of the tube replacement cost amounts to $1.00 per hour.

It is also anticipated that the X-ray machine will be amortized in five years and that the contractor will examine 100 of 500 (figure taken from reference (a))tankers during that time; thus, cost per tanker plus interest amounts to about $200.

<u>Darkroom Equipment</u>

Darkroom equipment, consisting of stainless steel master tank, stainless insert tanks 5 and 10 gal, 33 film hangers, drying tank, costs $1600.00

Installation and hardware	400.00
	$2000.00

<u>Labor</u>

According to the radiographic technique 3-min exposure can be expected per 3 ft weld; therefore, 1500 ft require 1500 min or 25 hr.

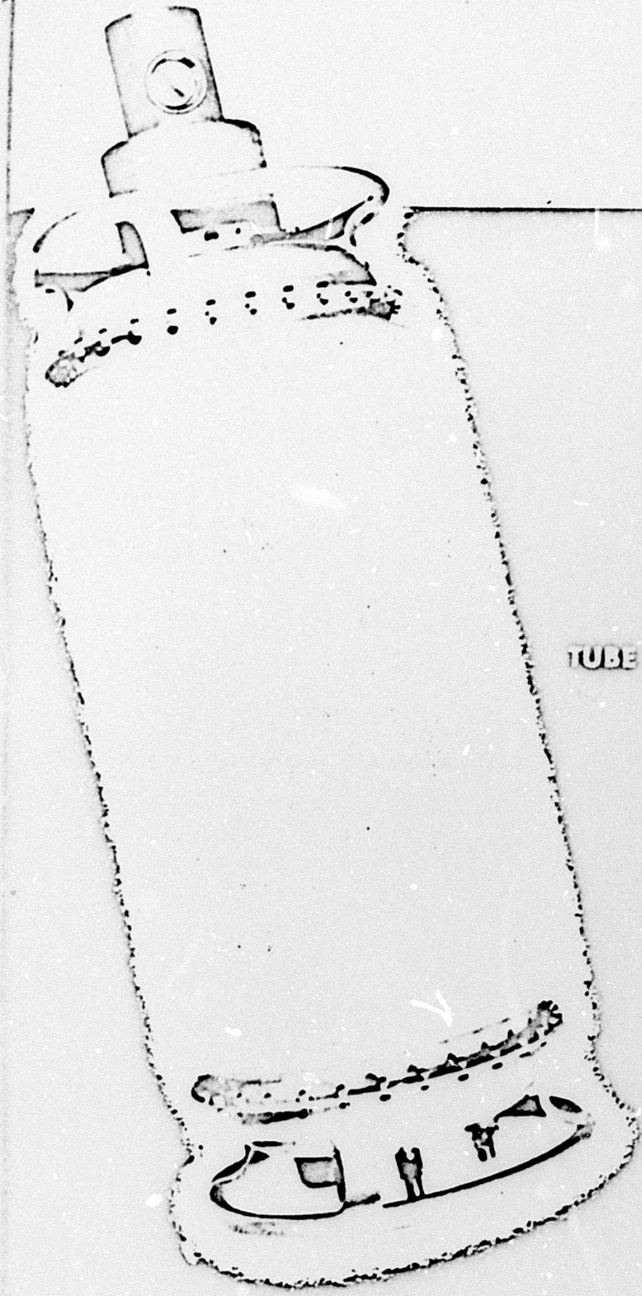
Considering a crew of four men, during the exposure of 3 min, another part of weld can be prepared for the next radiographic shot. One person of the crew will process he films.

Four men each $3.00 per hour represent $300.00 cost for 25 hr work. Total cost per examination of one tanker:

[redacted]

X-RAYS WHERE YOU WANT THEM

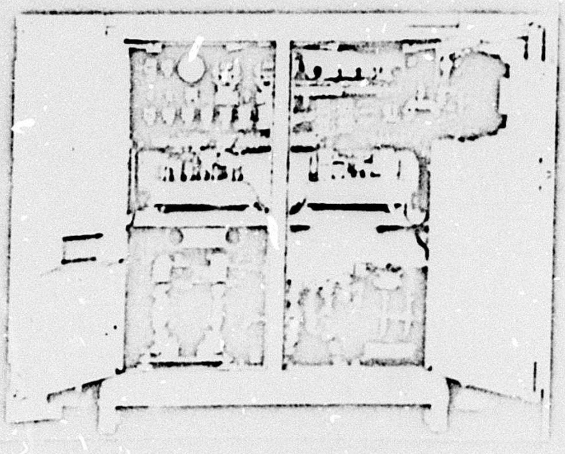
The General Electric Resotron 250 opens the door to a new era of industrial x-ray application. Here at last is a rugged, dependable, 250,000 volt industrial x-ray unit which is truly portable — truly lightweight — for x-rays where you want them. Embodying all the features possessed by conventional units in its voltage



THREE BASIC DESIGNS

TUBE HEAD (A)

POWER SUPPLY (D)



APPENDIX 2
(Cont'd)

Amortization of X-Ray Equipment	$200.00
Cost of X-Ray Tube	25.00
Amortization of Darkroom Equipment	25.00
Film cost	100.00
Labor cost	300.00
	$650.00
Profit	450.00
Total	$1100.00

GAMMAGRAPHIC METHOD

If instead of X-rays the gammagraphic technique is used, Cobalt 60 of 2000 mc (equivalent to 3000 mc radium) would be required. With that source, 3-ft weld could be gammagraphed in 3 min. It is assumed that moving the source, positioning it in a certain place, positioning new films, and removing the exposed films would require approximately 3 min per exposure, i.e. 6 min total time per 3 ft weld. With two crews and two sources, 1500 ft can be then gammagraphed in 25 hr. An additional 32 man-hours are assumed for film processing.

Cost of isotope Cobalt 60, 2000 mc	$100.00
Cost of container and accessories and photo chemical and processing equipment	500.00
	$600.00
Two units	$1200.00

Assuming that every 5 years (half-life time) a new isotope is purchased, the cost plus interest per inspection would be $ 1.20

Amortization for container and accessories	12.00
Amortization for darkroom equipment	25.00
Film cost	100.00
Labor cost: 132 man-hours, each $3.00	396.00
Total	$534.20
Profit	450.00
Grand total	$984.20

GEIGER COUNTER METHOD

The cost of the Geiger counter method cannot yet be estimated accurately because the present method will require additional development work in order to render it more economical. However, even considering the present method, the following figures prove its more expeditious performance as compared with the radiographic method mentioned by LCDR Hinkamp which costs $5000 per examination of one tanker.

APPENDIX 2
(Cont'd)

It can be assumed that three Geiger counters could simultaneously detect the absorption of three single Cobalt 60 sources, each 200 mc, in 3 in. length of weld. Three sources could be located in a common container which, in turn, is mounted on a small wheel cart. A total of 1 min would be required for operation and handling of the equipment. It is further assumed that four such units could be operated simultaneously by four crews, each crew consisting of two persons.

Under such conditions the following cost is computed per unit.

Cart	$ 50.00
Container for three Cobalt 60 sources	200.00
Three electric timers with counters	2400.00
Three preamplifiers and indicators	750.00
	$3400.00
4 units	$13,600.00

Cost per inspection:

Four Geiger tubes cost (1 spare tube)	$ 160.00
Amortization for 12 Cobalt 60 sources ($400) each 200 mc	5.00
Amortization of equipment	136.00
Labor: 1500 positioning by 4 crews of 2 requiring 1 min per one operation totaling 1500 = 25 hr @ $3.00/man-hour	600.00
	$901.00
Profit	901.00
Total	$1802.00

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